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Small hydropower plants in Spain: A case study

C. Alonso-Tristán*, D. González-Peña, M. Díez-Mediavilla, M. Rodríguez-Amigo, T. García-Calderón

Research Group SWIFT (Solar and Wind Feasibility Technologies), University of Burgos, Escuela Politécnica Superior, Avda. Cantabria s/n, 09006, Burgos, Spain

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ABSTRACT

A small hydropower plant in Spain is studied from an energetic and economic perspective. The viability of the facility is examined using the freeware software RETScreen. Calculated and standard operational data are compared, thereby demonstrating the feasibility of the project from all points of view. The study highlights the growing interest in renewable energies.

Contents

1. Overview of the European small hydropower sector

Small-scale hydropower is one of the most cost-effective energy technologies to be considered for rural electrification programmes in less-developed countries. It is also the main prospect for future hydro developments in Europe, where large-scale opportunities have either already been exploited, or would now be considered environmentally unacceptable.

In 2006, small hydropower (SHP) generated 41,000 GWh of electricity and accounted for over 13,000 MW of installed capacity in EU-27 which is enough to supply electricity to over 12 million households. This contributes to annual avoidance of CO_2 by 29 million tonnes, which translates into annual avoided CO_2 costs of about 377 M€ [1].

Hydropower is very dependent on a country's geography. This is demonstrated by the fact that over 90% of installed small hydropower capacity is concentrated in six member states of the EU-27: Italy, France, Spain, Germany, Austria and Sweden. In addition, Switzerland and Norway have a high SHP capacity, while the largest capacities in the new member states are in Bulgaria, the Czech Republic, Poland and Romania [1]. About 70% of economically feasible hydropower potential remains undeveloped in the world.

In 2006 there were nearly 21,000 SHP plants in the EU-27 and when Norway, Switzerland, Bosnia & Herzegovina and Montenegro

* Corresponding author. Tel.: +34 947 258925; fax: +34 947 258910.
E-mail address: catristan@ubu.es (C. Alonso-Tristán).

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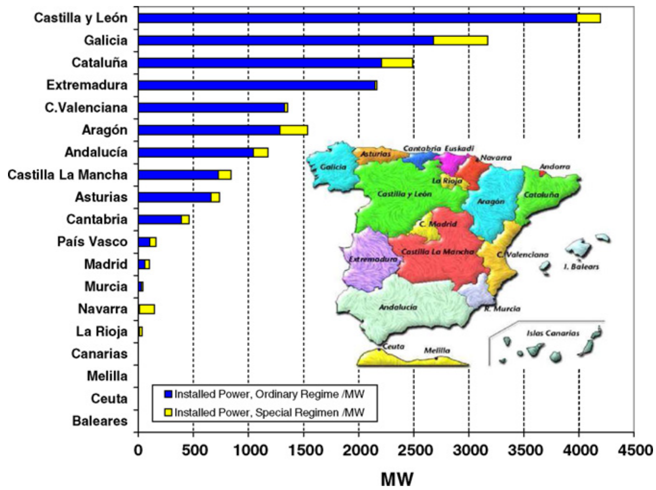

Fig. 1. Regional distribution of SHP capacity in Spain.
Source: Prepared from REE data in ref. [3].

are included, the number of SHP plants increases to a total of nearly 23,000. The range of investment costs can vary from 1000 €/kW (Greece, Spain, Bulgaria, Czech Republic, Estonia) to 12,000 €/kW (Germany). In terms of average SHP production cost, the range varies from 0.4 €cent/kWh (Bulgaria) to 17.4 €cents/kWh (Italy) [2].

1.1. SHP in Spain

Total hydropower electricity generated in Spain in 2009 was 23,862 GWh and 23% of this was produced by SHP facilities (5483 GWh) [3]. Total installed hydropower is 18,682 MW of which 1,974 MW (10.6%) is SHP. The regional distribution of hydropower capacity is presented in Fig. 1. The only evaluation of the SHP stations distributed throughout hydrographical river basins in Spain was completed in 1980 [4], from which it is assumed that the SHP potential is about 30,000 GWh/year. In 2009, hydropower supplied 1.7% of Spain's primary energy needs and 2.3% of its demand for electricity.

Development of renewable energies is a priority to which Spanish energy policy is committed. The National Action Plan for Renewable Energy in Spain (PANER) [5] is responsive to the requirements and methodology of the European Commission Directive 2009/28/CE [6] which set a binding target of 20% of total consumption from renewable energy sources by 2020. Within the European Commission, the Spanish model is a successful example of policies designed to promote renewables. The principle result is the volume attained by renewable electricity, which has established a structural position of the first order. In 2009, renewable technologies accounted for approximately 25% of total electricity generation and 12.2% of the gross final energy consumption in Spain.

The country's regulatory framework for electricity generation with renewable energies is structured through a feed-in tariff system. This operates by securing the payment of a tariff at the wholesale market price for superior technology. The additional financing is generated by levying the electricity tariff of individual users. Instead of an ordinary system of direct subsidies to producers, the costs are shared between conventional energy producers and consumers, in such a way that the resulting market price of electric energy production is reduced owing to the prioritization of renewable sources that enter the electricity production system. Therefore, consumers only finance renewable producers in sectors that are not covered by this effect.

Law 54/1997[7] of the Electrical Sector specifies two regimes for electrical generation:

- Ordinary regime for conventional power stations and
- Special regime.

Special regime generation activity includes electricity generation in power installations not exceeding 50 MW using renewable energy as the primary source of energy, or waste and those power installations that involve cogeneration as a technology with a high level of efficiency and considerable energy saving. This activity has economic and legal statutory benefits compared with the ordinary system that applies to conventional technologies. These facilities are regulated by the Royal Decree 661/2007 [8]. Two tariff systems exist with regard to repayment for renewable energies, which also apply to mini-hydro power installations:

- Fixed tariff: for renewable energies, established in different Royal Decrees on an annual basis.
- Variable tariff: market price plus a premium and a quality complement.

The evolution of the fixed tariff, the most widely chosen during the last 10 years throughout the SHP sector, is presented in Table 1. Among the measures that will boost future development is, primarily, the maintenance of an effective tariff system. The only quantitative evolution of the sector is from mini-power stations connected to the grid. Thus, the National Action Plan for Renewable Energy in Spain (PANER) [5] proposed regulatory measures designed to promote new SHP facilities and financial measures in order to improve and modernize existing facilities nearing the end of their useful life.

In this work, a case study of a small hydropower plant in Spain is presented. The SHP facility belongs to a small energy company that operates under a Special Regime for electricity production. It has been fully operational for 10 years. In the first place, this case study describes the SHP plant, and it goes on to examine the economic aspects of electricity production, its associated costs, and relevant grants and financial subsidies. The viability project of the facility has been simulated from RETScreen [9], comparing the real data to other possible economic scenarios. The results demonstrate, beyond doubt, the viability of small hydro power plants, even under unfavourable economic scenarios for investment.

2. The SHP case study in Spain

2.1. The facility description

The SHP case study (Astuwatt) is located on the banks of the River Pisuerga, in the town of Astudillo (Palencia), at the centre of the autonomous region of Castilla y León in Spain. It is a 400 kW grid-connected run-of-river type SHP plant with no dam or water storage. Its 640 m long trapezoidal bypass channel falls a total of

Table 1
Evolution of the fixed electrical tariff for electricity generation under the Special Regime applied to SHP in Spain (1998–2009).

	Year											
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
c€/kWh	6.778	6.685	6.365	6.365	6.383	6.491	6.548	8.964	8.979	7.382	8.248	8.500

Fig. 2. SHP facility: (a) aerial photography of the plant; (b) bypass channel; (c) return of the bypass to the main river.

2.9 vertical metres over its total length. The widths at the bottom and at the top of the channel are 6 m and 12 m, respectively. Once turbinated, the flow is channelled back to the main river. The aerial photographs in Fig. 2 illustrate (a) the plant, (b) the bypass channel and (c) the return to the main river.

The bypass channel was constructed by modifying an old irrigation channel. The bottom of the channel is sandy and only the final 150 m of its 640 m length, are to minimize loss through erosion. The plant is environmentally integrated [10] and therefore poses no threat to the indigenous flora and fauna.

The plant employs two 200 kW semi-Kaplan turbines, specifically designed for the project, that are 1.5 m in diameter, with an internal adjustable turbine runner tilted 15° from the horizontal. The design flow is 9 m^3/s. A multiplier element is used to adjust the speed of the turbine (190 rpm) to the speed of the electric generator (750 rpm). There are two 200 kW generators (Abb Motors, model M2BA 355 MLA8), one of which is specifically for the turbine. The output voltage of this generator is 400 V and a transformation system is used to convert the electricity to high voltage for input to the grid. An automatic system controls all mechanical components and records production data. Fig. 3 shows the turbines and the control system.

2.2. Economic data for the case study

The project grant for the operation was awarded in 1990 but it was not possible to complete the administrative process and fulfil all the necessary administrative requirements relating to permits until 1997. The running time was approximately 15 months and the system was powered up in June 1998.

The final price of the installation amounted to 1 M€, of which 30% of the total cost was financed through a bank loan with an interest rate of 9% for 7 years and a grant amounting to €24,000 was received from the Government of Castilla y León. Annual expenditure currently amounts to €32,000, which includes maintenance, staff costs and insurance.

Table 2 shows monthly electrical production from the outset of its functioning until 2009 and total annual electrical production is presented in Fig. 4. The facility tariffs its production at a fixed tariff, noted in Table 1. Since the outset, the installation has func-

Fig. 3. Different electromechanical elements of the SHP plant: (a) zenithal view of the turbines; (b) electric generator; (c) multiplier; (d) control system.

Table 2
Annual electrical production (GWh) of the SHP facility Asturwatt in the period under evaluation (1998–2009).

Month	Year											
	1998	1999	2000	2001[a]	2002	2003	2004	2005	2006	2007	2008	2009
Jan	0	130.10	233.21	0	113.18	142.72	244.57	134.71	132.18	201.90	123.13	187.25
Feb	0	108.43	177.26	0	90.29	127.50	204.09	132.64	108.57	194.21	114.11	194.24
Mar	0	72.22	122.69	0	142.48	168.99	223.86	154.32	215.29	224.04	116.32	222.52
Apr	0	52.63	137.30	0	104.80	190.37	182.14	139.66	186.33	203.09	171.97	151.07
May	0	76.25	201.89	0	32.05	183.68	132.69	89.71	73.53	206.93	220.05	94.56
Jun	45.65	49.61	137.88	0	20.07	119.47	100.07	110.07	49.28	190.66	127.72	87.19
Jul	154.15	90.86	144.79	0	97.07	109.24	94.02	145.75	61.79	141.29	104.37	136.08
Aug	134.50	74.74	141.84	0	70.68	131.65	90.98	127.68	69.13	123.75	108.53	118.72
Sept	103.46	30.67	45.00	0	0.00	66.01	48.59	21.83	20.41	124.99	97.68	58.20
Oct	24.48	55.58	7.99	28.80	43.25	81.79	31.53	0.19	49.83	59.16	0.54	8.60
Nov	7.56	199.22	114.41	74.97	94.74	130.75	92.92	83.60	131.31	27.58	41.85	18.21
Dec	0.22	186.48	14.40	67.07	150.87	187.23	113.80	106.08	200.14	28.18	175.96	76.65
Total	470.02	1126.80	1478.66	170.84	959.46	1639.41	1559.25	1246.24	1297.78	1725.80	1402.22	1353.30

[a] The electrical production was null from January to September of 2001 due to damage caused by a major flood and subsequent repairs to a large part of the electromechanical elements of the installation.

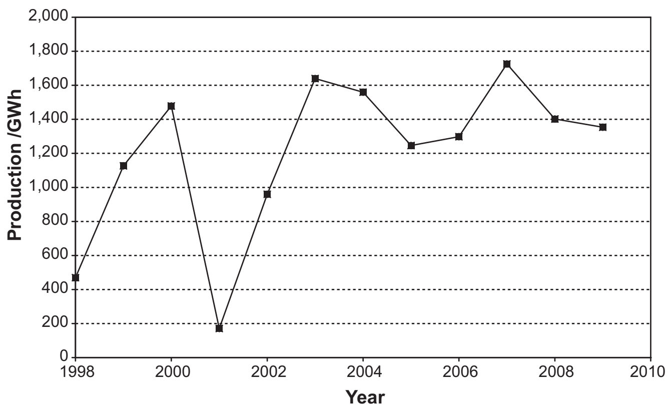

Fig. 4. Annual total production (MWh) of the SHP facility from 1998 to 2009.

tioned for an average of 3,135 h per year, except during 2001, when the plant needed repairs following extensive flooding. This value is within the range of the technology and the design flow [11] used in the project. However, the price per kW installed (2500 €/kW) is higher than the average estimated by industry associations [2]. This is mainly due to increased costs associated with the use of self-designed turbines, which required the adaptation of other elements in the plant and the use of two turbines instead of one, in order to adjust the capacity of the facility to the river flow.

3. RETScreen study of the facility

The previous section presented a case for a viable and cost-effective installation in a particular economic scenario. Opportunities for implementing commercially viable, energy efficient and renewable energy technologies (RETs) are often missed these days, because many planners and decision-makers still do not routinely consider them at the critically important, initial planning stage, even though technologies such as small hydropower installations have proven their reliability and cost-effectiveness in similar situations elsewhere. Specific procedures regarding design and economic viability studies of small hydropower plant projects have been developed [12–14], in order to address and integrate at a pre-feasibility, planning stage, perspectives that consider all the potential obstacles that can arise.

RETScreen software [9,15] is capable of assessing RETs viability factors such as energy resources available at the project site, equipment performance, initial project costs, "base case" credits, on-going and periodic project costs, avoided cost of energy, financing, taxes on equipment and income (or savings), environmental characteristics of energy displaced, environmental credits and/or subsidies and decision-maker defined cost-effectiveness.

Moreover, the RETScreen software integrates a series of databases that help to overcome the costs and difficulties associated with gathering meteorological data, product performance data, etc. Hence, worldwide meteorological data has been incorporated directly into the RETScreen software. This meteorological database includes both the ground-based meteorological data and NASA's satellite-derived meteorological data sets. The RETScreen's hydroelectric model can be used anywhere in the world, but the only available hydrological data is from Canada. However, the user can introduce data from any other source. The software has been widely used to study all types of renewable energies including: small hydropower [16], photovoltaic power [17,18], solar water heaters [19], wind and small wind projects [20], combined heat and power facilities [21], hybrid systems [22], among others. The application of this tool for the proposed case study will demonstrate its capacity to perform pre-feasibility studies anywhere in the world and will expand the study for application in other design options and financing as well as different economic scenarios.

Seven worksheets are provided in the small hydro project workbook file:

- Energy model;
- Hydrology analysis and load calculation;
- Equipment data;
- Cost analysis;
- Greenhouse gas emission reduction analysis;
- Financial summary;
- Sensitivity and risk analysis

Fig. 5 presents a flow diagram of the computerized RET's assessment tool. Greenhouse gas emission reduction and sensitivity and risk analyses are optional.

3.1. The energy model

The first step, referred to as the "energy model", requires the user to collect basic information concerning the site conditions as may be necessary: latitude and longitude, available head, or drop in elevation. These data are presented in Table 3 in relation to this case study.

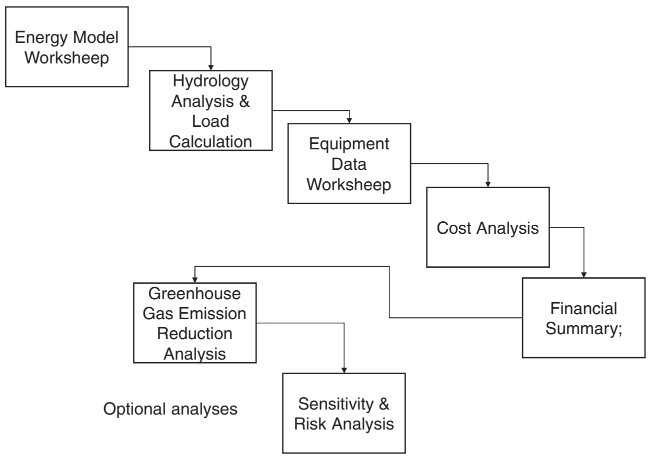

Fig. 5. RETScreen model flow diagram.

Table 3
Energy model data for the SHP project.

	Unit	Location of meteorological data	Location of the project
Latitude	°N	42.0	42.2
Longitude	°E	−4.5	−4.3
Drop in elevation	M	757	780
Heating design temperature	°C	−2.3	
Air conditioning design temperature	°C	26.1	
Soil temperature amplitude	°C	19.4	

3.2. Hydrology analysis and load calculation

RETScreen calculates the estimated renewable energy delivered for SHP projects, based on the adjusted available flow (adjusted flow–duration curve), the design flow, the residual flow, the load (load–duration curve), the gross head and the efficiencies/losses.

The flow–duration curve of the River Pisuerga in the facility site has been calculated from data compiled by the Confederación Hidrográfica del Duero [23], the results of which are presented in Fig. 6. It also includes the design flow of the turbines and the biological indicators of the river flow.

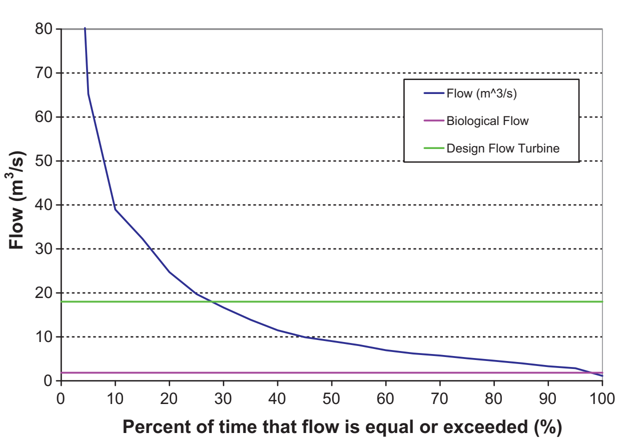

Fig. 6. Flow duration curve for the River Pisuerga.
Source: Prepared from Confederación Hidrodráfica del Duero data in ref. [23].

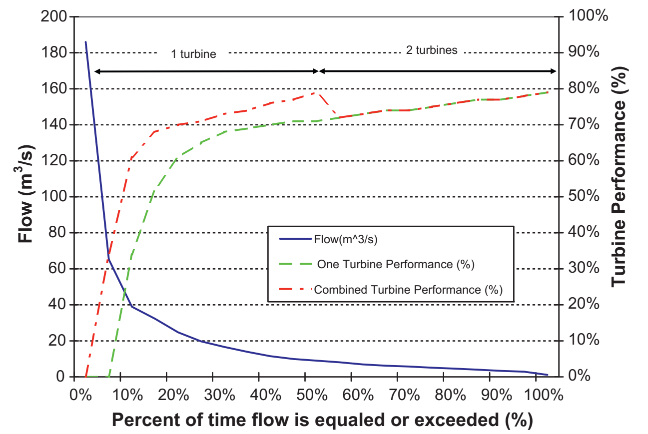

Fig. 7. Turbine performance as a function of the flow duration curve and the number of working turbines.

3.3. Equipment data

The data on small hydro turbine efficiency can be entered manually or can be calculated by RETScreen. Turbine performance is calculated at regular intervals on the flow–duration curve. Plant capacity is then calculated and the power–duration curve is established. Available energy is simply calculated by integrating the power–duration curve. In the case of a central-grid, the energy delivered is equal to the energy available. The calculation involves comparing the daily renewable hydro-energy available to the daily load–duration curve for each of the flow–duration curve values.

For this case study, the efficiency as a function of the flow–duration curve and the number of functioning turbines is presented in Fig. 7 and a summary of results in Tables 4 and 5.

3.4. Cost analysis

During the "cost analysis" step, a detailed cost analysis is performed taking into account initial costs and annual costs (maintenance, staff and insurances) involved in the project. Fig. 8 presents the distribution of initial expenses.

3.5. Greenhouse gas emission reduction analysis

The RETScreen has the capacity to estimate the amount of green house gases (GHG), which could be avoided as a result of using renewable energy sources. The required input data is the fuel type used in the specific country in question, which is selected as "All fuel types" and the transport and distribution losses are calculated

Table 4
Summary of the technical performance characteristic of the semi-Kaplan turbine of Asturwatt.

Design flow	18 m^3/s
Design coefficient	4.5
Turbine peak efficiency	78.5%
Flow at peak performance	13.5 m^3/s
Turbine efficiency at design flow	78.1%
Maximum hydraulic losses	35%
Miscellaneous losses	2%
Availability	97%

Table 5
Equipment data analysis: summary of results.

Power capacity	363 kW
Available flow adjustment factor	97%
Electricity exported to grid	1479 MWh

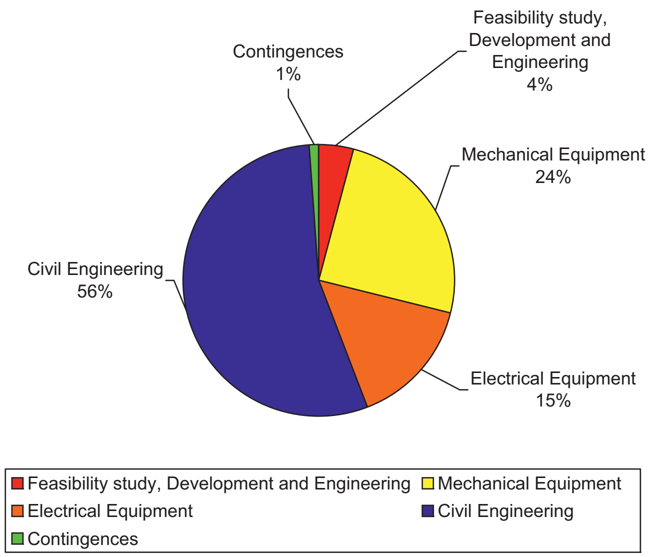

Fig. 8. Summary of the initial costs of the facility.

at 7.5% for Spain, as a developed country. The model GHG emission factor is estimated to be 0.411 tCO_2/MWh and the net annual GHG emission reduction is 607.4 tCO_2/year.

3.6. Financial summary

A number of different economic and financial feasibility indices were calculated such as the year-to-positive cash flow, Internal Rate of Return (IRR), return on investment (ROI), and Net Present Value (NPV). The results are presented in Fig. 9, in which the calculated RETscreen accumulated cash flow results over 50 years of operation can be compared with the usual ones over the 10 years of operation. Table 6 summarises these results. The RETscreen calculations are based on 4.54% after-tax IRR assets and a simple payback over 11.2 years, while the real results over 10 years are 4.1% and 12.5 years of payback. NPV for the plant is €2,349,625, very close to the calculated figure, drawn from an extrapolation of the actual data which amounts to €2,012,466.

3.7. Sensitivity and risk analysis

Different economic scenarios were studied in order to indicate the viability of the installation, by varying the electricity price (EP)

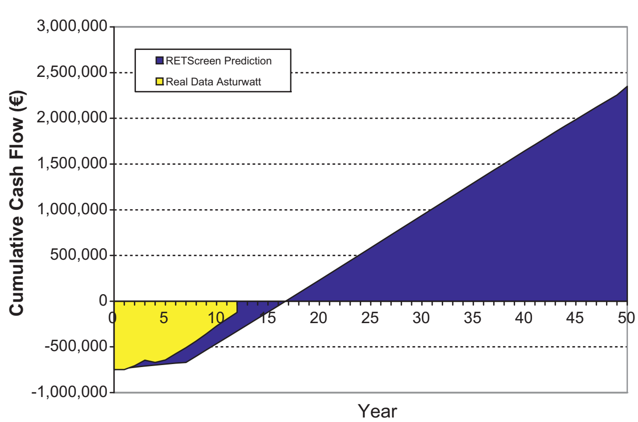

Fig. 9. Summary of financial analysis: cumulative cash flow calculated by RETScreen over the estimated cycle of life of the plant and the actual cash flow for the 10 years of operation.

Table 6
Summary of financial results of the SHP project calculated by RETScreen.

Pre-tax IRR-equity	9.2%
Pre-tax IRR-assets	6.9%
After-tax IRR-equity	6.2%
After-tax IRR-assets	4.5%
Simple payback	11.2 year
Net present Value (NPV)	2349625 €
Annual life cycle savings (50 years)	46992 €/year
Benefit–cost (B–C) ratio	4.07
Debt service coverage	1.55
Energy production cost	50.52 €/MWh.

and the CPI (Consumer Price Index). CPI affects the annual cost of the plant (insurance, staff and maintenance). The electricity price is fixed every year according to economic and political parameters. Assuming that the plant has a lifetime of 50 years, the minimum EP increment was calculated in order to offset the increased fixed costs incurred by the CPI. The electricity price was adjusted in accordance with the annual fixed tariff referred to as the CPI, with or without governmental subvention. The CPI was calculated on the basis of a fixed annual increase of 2% or a variable limited rate of ±2% annually. As results of these calculations a revalorization of EP slightly lower than the CPI (98%) is necessary in order to achieve a positive IRR.

4. Conclusions

In this paper, a real case of a 400 kW grid-connected SHP plant has been presented. The installation has functioned at full capacity over the past 10 years and has presented positive energy efficient, environmental and economic results. The total amount of generated electricity amounted to 17,070.4 MW at the end of 2009 and the plant has avoided the emission of 607.2 tCO_2/year. A total repayment period of 12 years was calculated, after allowing for financial subsidies and grants. The installation is assumed to have estimated lifetime of 50 years.

A pre-feasibility study was conducted using RETScreen software in order to extend the case study to other economic scenarios and demonstrate the viability of these types of projects. The energetic and economic results generated by the RETScreen software closely approximate the usual ones, which demonstrates the capacity of the RETScreen to analyse small hydro projects. The estimated energy production cost is 5 c€/kWh, a value within the margins calculated by various industrial associations that work in the sector [24].

The sensitivity analysis that changes the economic variables has demonstrated that the installation is, from an economic point of view, profitable, even without the feed-in-tariff subvention system, provided that the electricity price is adjusted to the CPI changes. However, all of the advantages outlined in this study are in stark contrast to problems over drawn out administrative procedures and red-tape in the various local and regional authorities when processing permits, and granting licenses and environmental concessions. A centralized procedure is clearly required, which would facilitate the implementation of facilities and prevent delays and loss of competitiveness.

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